NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1868

CORRELATION OF PILOT OPINION OF STALL WARNING WITH FLIGHT MEASUREMENTS OF VARIOUS FACTORS WHICH PRODUCE THE WARNING

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SUMMARY

A study was made to correlate pilots' opinion of the stall warning properties of 16 airplanes with a number of quantitative factors obtained from time history records for speeds near the stall. The results indicate that, in general, the stall warning was considered satisfactory by the pilots when characterized by any of the following qualities: (a) airplane buffeting at speeds from approximately 3 to 15 miles per hour above the stalling speed and of a magnitude to produce incremental indicated values of normal acceleration factor of 0.04 to 0.22, (b) preliminary controllable rolling motion of 0.04 to 0.06 radian per second occurring anywhere within a range from approximately 2 to 12 miles per hour above the stalling speed, and (c) rearward travel of the control stick of at least 2.75 inches during the 15-mile-per-hour speed range immediately preceding the stall. The magnitude of the rolling velocity in the complete stall influenced the degree of buffet and stick movement required for satisfactory warning.

INTRODUCTION

The need for the establishment of quantitative design criteria for describing the flying qualities of aircraft has been generally well recognized and met during the past several years. These criteria evolved from an analysis of a large volume of quantitative flight data correlated with pilot opinion and were reported originally in reference 1. Later these various criteria were adapted and revised to apply specifically to military aircraft.

At present it is generally possible to compare all the flying-qualities characteristics with specific quantitative requirements except for the characteristics regarding stall warning and the behavior of the airplane in the complete stall. Some work relating to quantitative factors in the complete stall has been presented in reference 2.

In order to provide a preliminary basis for a quantitative evaluation of the stall-warning characteristics of an airplane, an effort is made herein to correlate a number of measurable factors with pilots' opinion of the adequacy of the stall warning. The data for this study were obtained from flight tests of various airplanes at the Ames Aeronautical Laboratory.

INSTRUMENTATION

Standard NACA recording instruments synchronized by an NACA timer were used to record normal acceleration, stick force, elevator angle, roll and pitch velocities, airspeed and altitude. The accelerometer was secured approximately at the test center of gravity for each airplane and the control-position recorders were located as close to the control surfaces as possible. In some instrument installations the pilot was able to identify the first indication of stall warning in the time history by means of a film marker.

A free-swiveling airspeed head mounted approximately one chord length ahead of the wing leading edge was used in determining calibrated airspeed.

TESTS

The data have been taken during stalls of 16 airplanes ranging from single-engine fighter to four-engine bomber types. The tests were made with the center of gravity at the normal position, within an altitude range of 4,000 to 12,000 feet, and in straight flight by gradually approaching the stall with the normal acceleration factor as close to unity as possible. For the various tests, pilots' notes were available in which opinions of the stall warning were expressed. The airplanes were flown by NACA test pilots having varied backgrounds of naval, military, research, and commercial flying experience. Five pilots participated in the tests, although each airplane was not necessarily flown by all five pilots.

ANALYSIS OF DATA

The current flying-qualities specifications state that the approach to the complete stall shall be accompanied by a definite stall warning consisting of one or more of the following, preferably the first: (1) buffeting and shaking of the airplane and controls, (2) marked increase in rearward travel of the control column or marked increase of control force for further speed reduction, (3) preliminary development of the stall through small amplitude pitching and rolling motion. The requirements also state that the stall warning shall occur at a speed not less than 1.05 or more than 1.15 times the stalling speed for each of the various flight configurations.

Quantitative values of the following factors were considered in an attempt to provide correlation with pilot opinion of the adequacy of the stall warning: (1) the amount of airplane buffet indicated by the accelerometer, (2) the amount of shaking of the elevator shown by the control position recorder, (3) the amount of elevator buffet shown by the stick force recorder, (4) the maximum amplitudes of roll and pitch velocities, and (5) the amount of change in elevator stick position and control force prior to the stall.

During the analysis it was found that a number of the aforementioned items did not correlate with the pilot's impression of the adequacy of the stall warning. Control shaking shown by the elevator control-position recorder did not give a good indication of the resultant feel of the control stick experienced by the pilot probably because of play and/or stretch in the control system. Another item which was eliminated was the amount of buffet shown by the force variation at the control-stick grip. This showed no consistent correlation with buffet or shaking of the controls possibly because of friction in the control system and the fact that the force recorded depended upon the amount of restraint supplied by the pilot. The measurement of small amplitude pitching motions was not used since in no case was pitching motion encountered without the presence of either rolling motion or airplane buffet. For this reason it was felt that measurement of factors tending to produce pitching motion were covered satisfactorily by the measurements of either preliminary rolling motion or airplane buffeting. Sufficient data were not available to establish a relationship between pilot opinion of stall warning and the amount of increase in control force for further speed reduction. The only items found which produced consistent quantitative measurements and could be correlated with pilot observations of the stall warning were normal acceleration, rolling velocity, and elevator-control position.

It should be noted that the absolute magnitude of the values given by the accelerometer are in error due to inability of the accelerometer to measure true changes in acceleration except for very small amplitudes or frequencies far lower than its natural period. For the range of buffeting frequencies encountered (approximately 6 to 14 cycles per second), the accelerometer readings were approximately correct for incremental values of 0.05 from a mean value of about 1, but increased in error with increase in incremental acceleration so that at an incremental acceleration factor of 0.25 the low-frequency incremental acceleration values were 7 percent low and the high-frequency incremental values were 25 percent low.

RESULTS AND DISCUSSION

Pilot opinion of the stall warning has been correlated with the results of the measurements obtained from the accelerometer, roll-turnmeter, and elevator-control position recorder, and are presented herein. In the discussions it should be noted that the acceptance of each stall warning is based on pilot opinion of that particular type of warning.

The results of the measurements obtained by the accelerometer are shown in figure 1, in which the indicated values of the incremental normal acceleration factor A_Z (measured from a mean value), due to buffeting at various speeds above the stall, are shown with pilot opinion of the stall warning. In this figure, the points of initial buffet and buffet at stall have, in most cases, been connected by a straight line, since it was found that the variation of incremental indicated acceleration factor with airspeed was approximately linear. Boundaries have been drawn showing the satisfactory and unsatisfactory regions as determined from the comments of several pilots.

The incremental value of A_Z measured at the first point of airplane buffet was approximately 0.04 which, judging from the indication given by the pilot's film marker, was the smallest change in acceleration that the pilot was able to detect. The ability of the pilot to detect the lower limit of buffeting is influenced by a number of factors such as its frequency, the presence of other transverse vibrations, and by the intensity of noise (reference 3). In this regard jet-propelled aircraft would possibly offer more ideal conditions for detecting stall warning produced by buffeting.

Judgment of whether or not the stall warning is satisfactory at the first indication of airplane buffet is dependent not only on the initial amplitude but also on the speed above stall where buffet first begins and on how rapidly the buffet increases in amplitude with decreasing airspeed. A region on the right of figure 1 is shown where buffeting did not serve satisfactorily as a stall warning for a number of reasons. At speeds in excess of approximately 15 miles per hour above the stall the buffeting was too far removed from the complete stall to serve as a satisfactory warning of the approaching stall. While it was not possible to accurately establish this speed due to lack of data the point selected corresponds approximately to that used in the current flying-qualities specifications. Another unsatisfactory aspect of the early buffet is that the buffet might build up to such great magnitude as the stall is approached that the pilot fears structural damage to the aircraft. This region where structural damage to the airplane was expected is shown in the upper part of figure 1. In addition, large magnitude buffeting occurring over a long period before the stall would be particularly objectionable to a pilot in landing.

The boundary for the lowest speed above the stall where the pilot would accept buffeting as a satisfactory stall warning is somewhat obscure due to the interaction of several factors. However, the general trend of data seems to indicate that buffet should occur approximately 3 miles per hour above the speed of stall for a satisfactory warning of the approaching stall. In some cases it was found that the pilot would consider the warning satisfactory with little or no airspeed margin above the stall as shown on the extreme left-hand part of figure 1. This condition was probably due to the fact that sometimes a finite time delay existed between the attainment of a minimum airspeed value and the complete flow breakdown producing the stall. This time delay amounted to as much as 3 or 4 seconds for some airplanes. During this period if the pilot experienced buffeting and the roll-off in the complete stall was not too severe, the warning may have been judged satisfactory.

The tendency for the behavior of the airplane in the complete stall to influence pilot opinion of the stall warning is shown in figure 2 where the amount of buffet and the roll-off in the complete stall are given with pilot opinion of the stall warning. These data (fig. 2), judging only from the magnitude of buffet at the complete stall appear to indicate that correspondingly larger values of buffet are required for satisfactory warning as the magnitude of roll-off in the complete stall increases. Another point of interest shown in this figure, which ordinarily may not be realized, is that relatively large amplitudes of buffet can occur with large values of roll-off at the stall.

The values of preliminary rolling motion preceding the stall, presented with pilot opinion of the stall warning, are shown in figure 3. These data indicate that the rolling velocity must be at least 0.02 radian per second (1.15 deg/sec) to be perceptible to the pilot as a stall warning. It is also shown that the magnitude of the rolling motion must be at least 0.04 radian per second to be considered satisfactory as a stall warning. Because ample data were not available, no attempt was made to establish an upper limit for the value of rolling velocity required for a satisfactory stall warning. In one case at a rolling velocity of 0.22 radian per second the pilot considered the roll-off to be more characteristic of the complete stall rather than the stall warning as he stated, "roll too large to be considered as a warning." From this it appears that the upper limit of the value of rolling velocity which could be used as an acceptable stall warning would not exceed 0.22 radian per second and would probably be somewhat lower. Indications are that the pilots generally did not consider rolling-velocity values in excess of approximately 0.06 radian per second as a satisfactory stall warning since information was nonexistent above this value. The results shown in figure 3 appear to indicate little or no influence of change in airspeed on the magnitude of the value of rolling velocity required for a satisfactory warning. From the data available, the speed range over which stall warning was satisfactory has been established as 2 to 12 miles per hour above the stalling speed. In most cases the rolling motion was of an oscillatory nature with a frequency of the order of 0.3 cycle per second. In a few cases the acceptance of the rolling motion as a warning was influenced by the presence of another type of stall warning; that is the pilot stated, "stall warning occurred in the form of rolling and buffeting of the airplane."

The data of figure 4 show the rearward movement of the control stick (at the grip) for the 15-mile-per hour range immediately above the stall correlated with pilot opinion of the stall warning. For ease in evaluating this type of stall warning, the stick movement-airspeed variation has been presented as a straight line. In figure 4 three regions are shown defining the acceptability of stick movement as a stall warning, since it was found that the pilots' opinion of this stall warning was influenced by the amount of roll-off experienced in the complete stall. The regions shown in figure 4 have been established with aid of data from figure 5 which show the relationship between the stick travel and the roll-off at the stall for the last 15 miles per hour above the stall correlated with pilot opinion of the stall warning. In region (1) of figure 4, a stick movement greater than 2-3/4 inches was considered satisfactory for values of rolling velocity up to 0.3 radian per second. (For the tests covered herein, data were nonexistent for large values of stick travel with roll-off velocities beyond 0.3 radian per second. See upper portion of fig. 5). In region (2) the stall warning was found to be marginal, depending on the magnitude of the roll-off at the stall; that is, the warning was satisfactory for small values of rolling velocity and unsatisfactory for large values (data taken from the middle region in fig. 5). One and three-quarters inches or less of stick travel was unsatisfactory as a warning regardless of the degree of roll-off at the stall (region 3).

CONCLUSIONS

A correlation of pilot opinion of the stall-warning characteristics of 16 airplanes with quantitative factors taken from time history records at speeds near the stall indicated the following:

1. In general, stall warning was considered satisfactory by the pilots when any of the following conditions was present: (a) airplane buffeting occurring at speeds from approximately 3 to 15 miles per hour above the stalling speed and resulting in an incremental indicated acceleration factor of 0.04 to 0.22; (b) preliminary controllable rolling motion from 0.04 to 0.06 radian per second occurring anywhere within a range from approximately 2 to 12 miles per hour above the stalling speed; and (c) rearward movement of the control stick at the grip of at least 2.75 inches during the 15-mile-per-hour speed range immediately preceding the stall.

2. The degree of buffeting and rearward movement of the control stick considered satisfactory as a stall warning was influenced by the magnitude of the rolling velocity in the complete stall.

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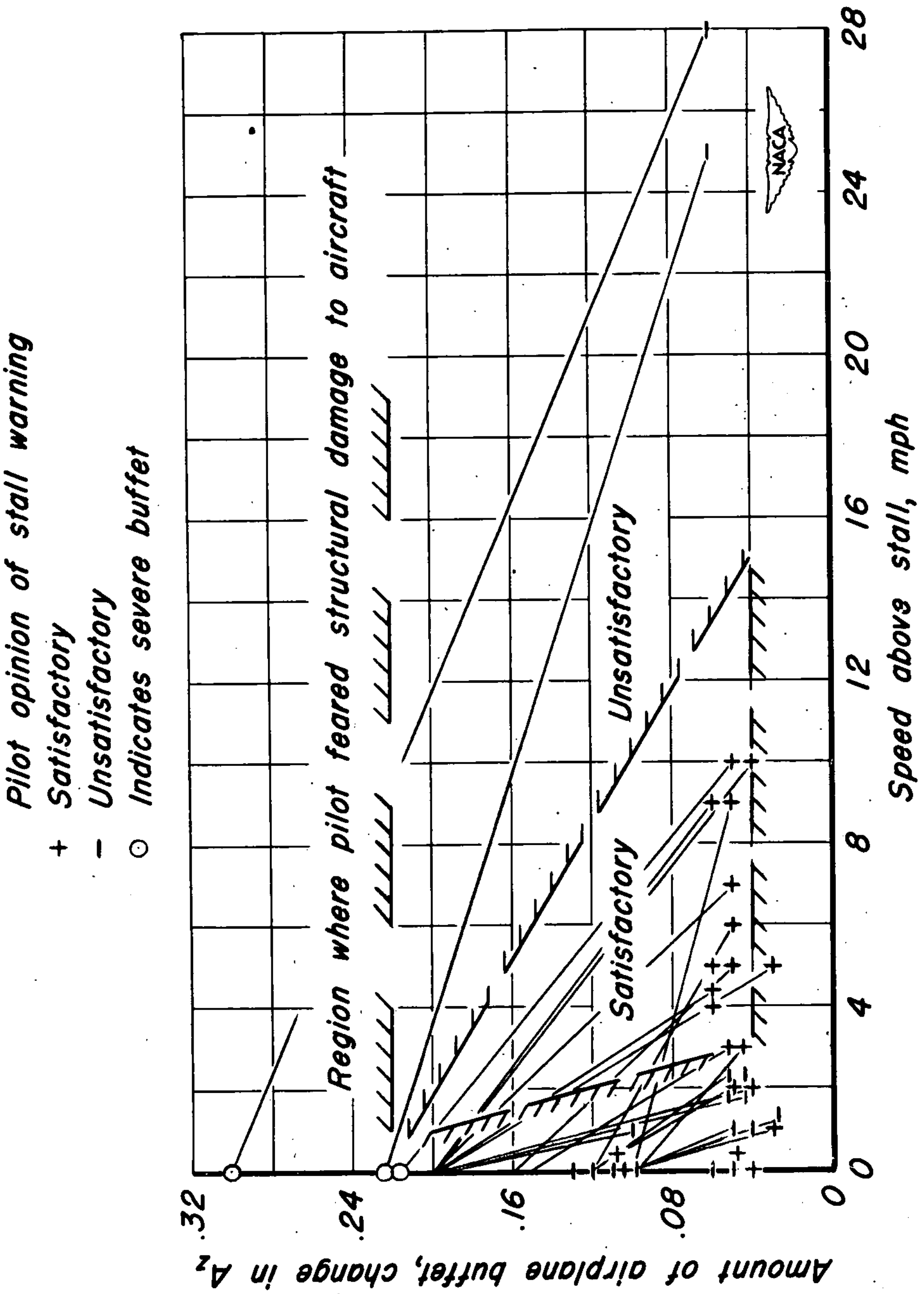

Figure 1.- Correlation of pilot opinion of stall warning with airplane buffet at various speeds above the stall.

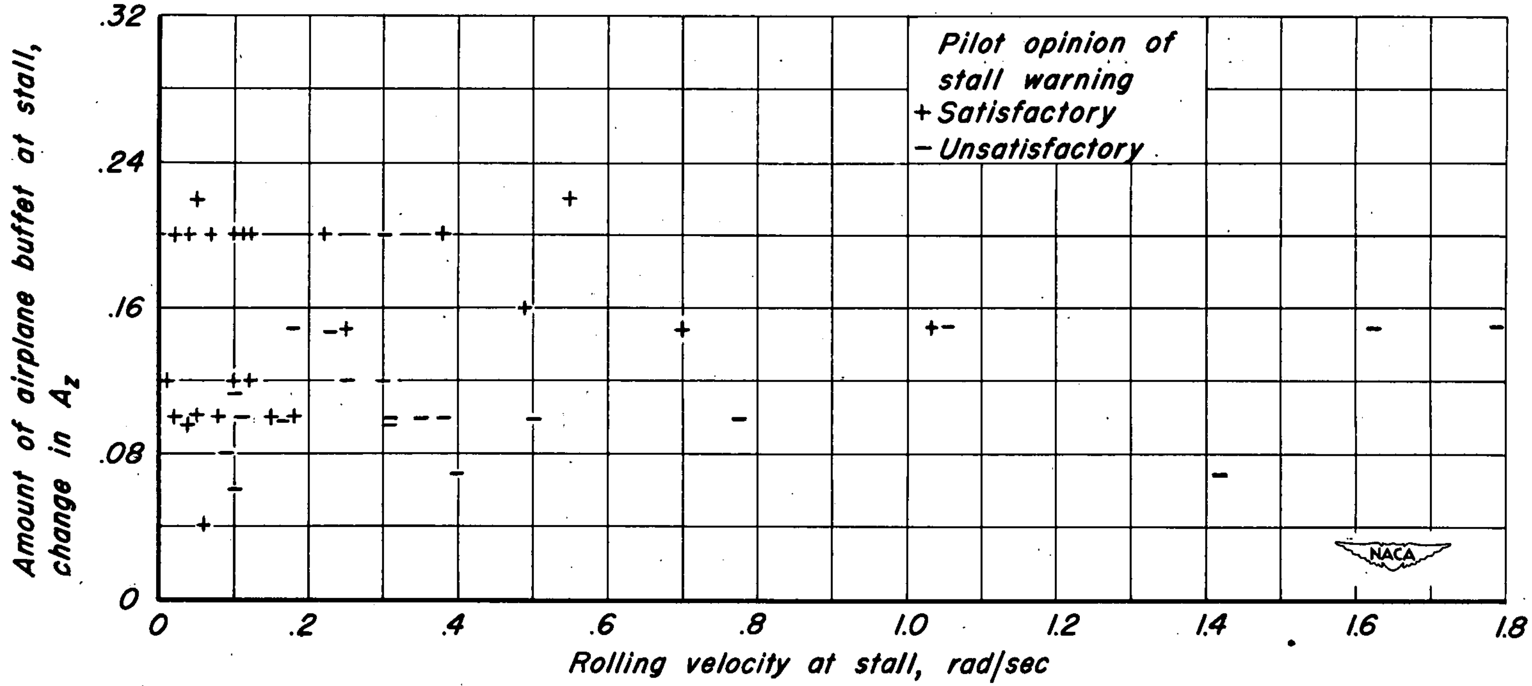

Figure 2.- Correlation of pilot opinion of stall warning with airplane buffet and roll off at the stall.

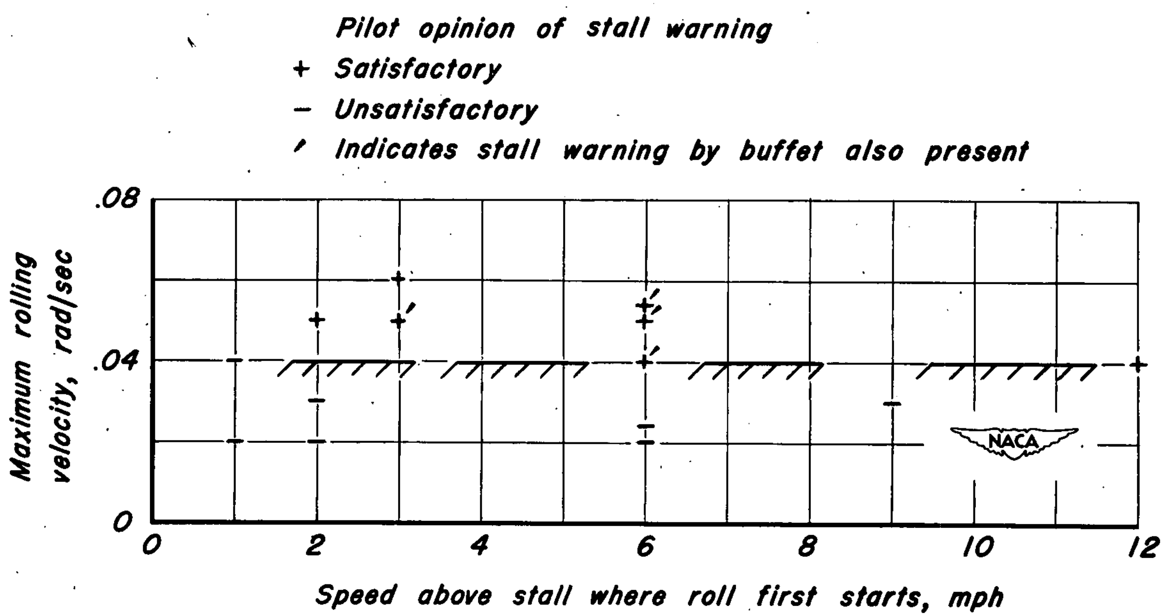

Figure 3.- Correlation of pilot opinion of stall warning with rolling velocity at various speeds above the stall.

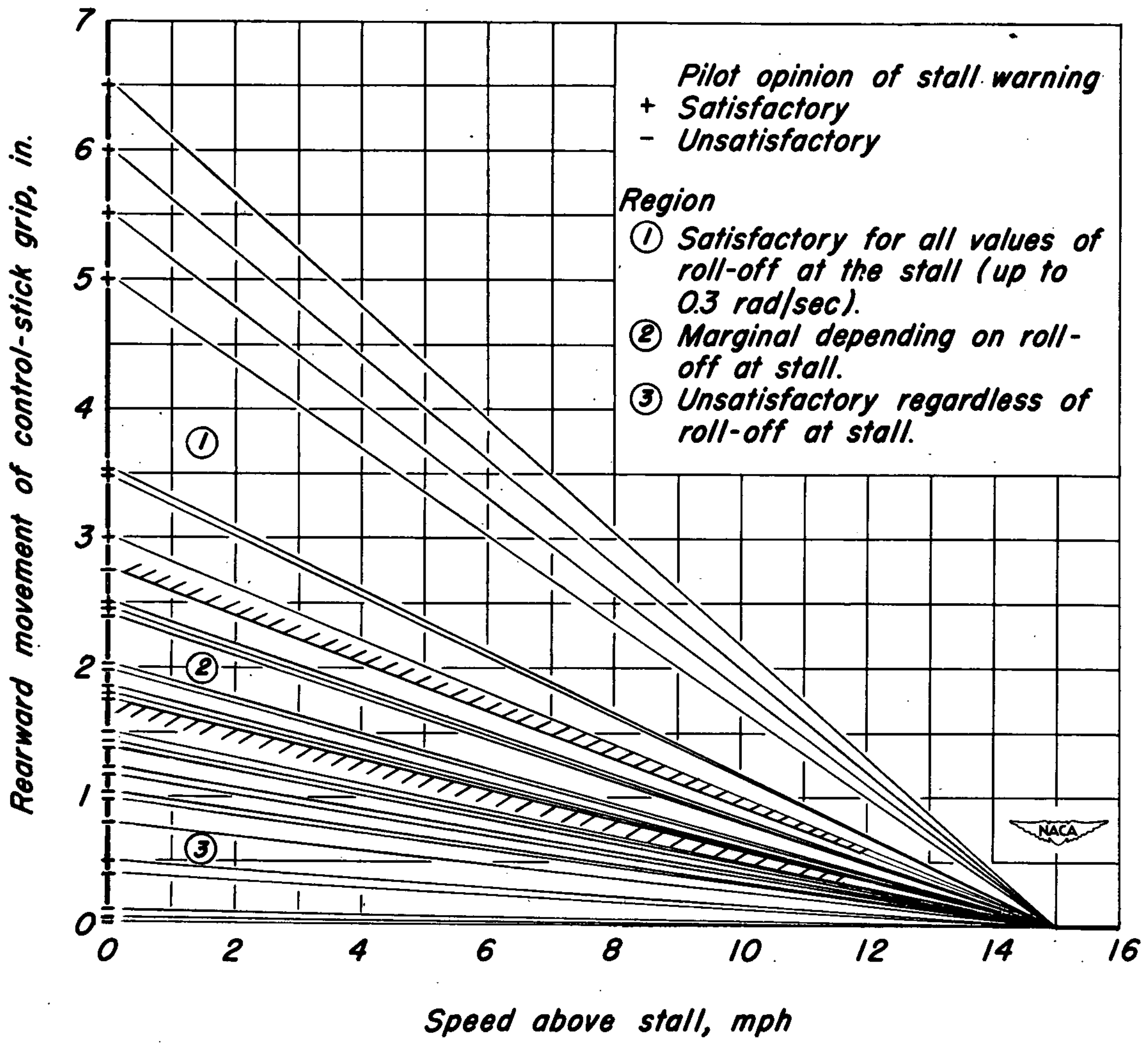

Figure 4.- Correlation of pilot opinion of stall warning with rearward movement of control stick in the speed range immediately above the stall.

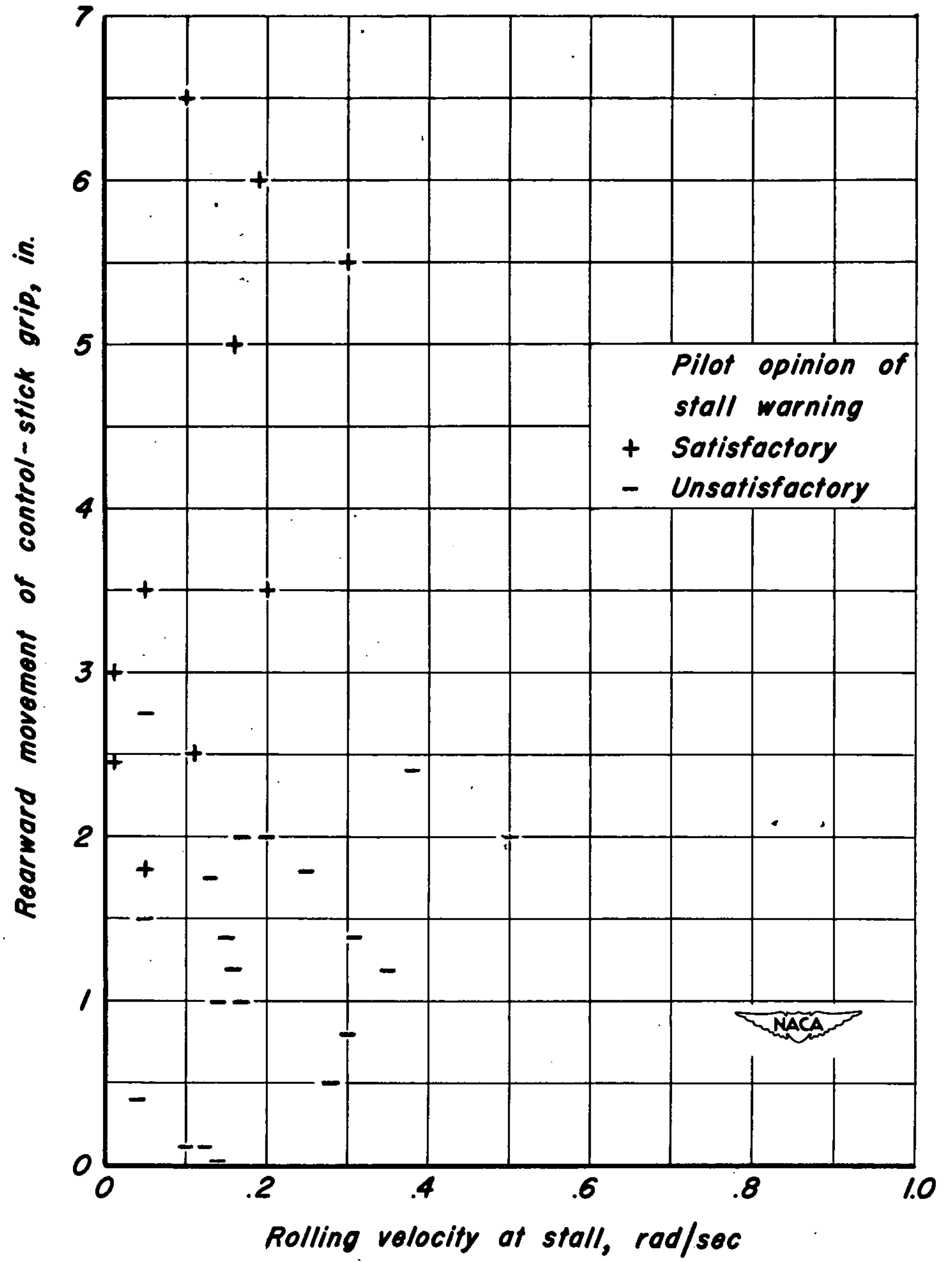

Figure 5.- Correlation of pilot opinion of stall warning with rearward movement of control stick for the last 15 miles per hour above the stall and roll off at the stall.